Coronary Vessels and Cardiac Conduction

Introduction to the Electricity Island

This first Electricity lesson is about the **coronary arteries**. Being arteries, they follow all the same principles taught in the Hemodynamics island. They have a tunica media that is separated from the tunica adventitia and tunica intima by the outer and inner elastic lamina, respectively. They are lined with endothelium. They are special because they perfuse the heart and fill primarily in diastole. They perfuse the myocardium. We bring up coronary arteries here, at the start of the Electricity island, because some of them perfuse the electrical conduction system. And although there is a great deal of variability in the final outcome of coronary perfusion, for the most part, occlusion of a coronary artery—which would lead to myocardial death—can be mapped to a 12-lead ECG. Atherosclerosis of coronary arteries is coronary artery disease (chronic ischemic heart disease and myocardial infarction) and intimately related to the cardiac conduction system.

In this lesson, we cover the coronary arteries and cardiac veins and the anatomy of the cardiac conduction system. This primes you for the rest of the Electricity island, which focuses on action potentials, rhythms, ECG, and arrhythmia pathogenesis and treatment.

Coronary Artery Perfusion

The coronary arteries provide oxygen to the cardiac tissue. The heart has a very **high oxygen demand**, even at normal workloads—at a resting heart rate. The heart has the **largest oxygen extraction** of any tissue, meaning that the blood returning from the heart muscle through the **cardiac veins** has the **lowest oxygen** content. At a normal resting heart rate, with minimal cardiac work and the lowest oxygen demand, 80% of the oxygen is extracted from the blood.

The heart is fed by **two main coronary arteries**, the right and left coronary arteries, which arise from the **proximal ascending aorta** just distal to the aortic valve. These originations are called **coronary ostia**. There is almost no redundancy in arterial flow to the heart, meaning that any one region of the heart is supplied by one artery. Which artery supplies which region can vary significantly among individuals, but all the same territories are irrigated. The myocytes are permanent cells—the myocardium a G_0 phase tissue.

The coronary arteries are just arteries of the heart, possessing all of the same features as any other artery. Because the ostia are just distal to the aortic valve, they are occluded when the aortic valve opens in systole, so the coronary arteries cannot be perfused during systole. The blood is being pushed forward through the arterial system. During diastole, the transmural pressure stored in the elastin fibers of the aorta is released, translated into luminal pressure propelling the blood forward. The aortic valve is closed, so the blood has nowhere to go but forward—except through the coronary ostia, which are now open. The **coronary arteries are perfused during diastole**.

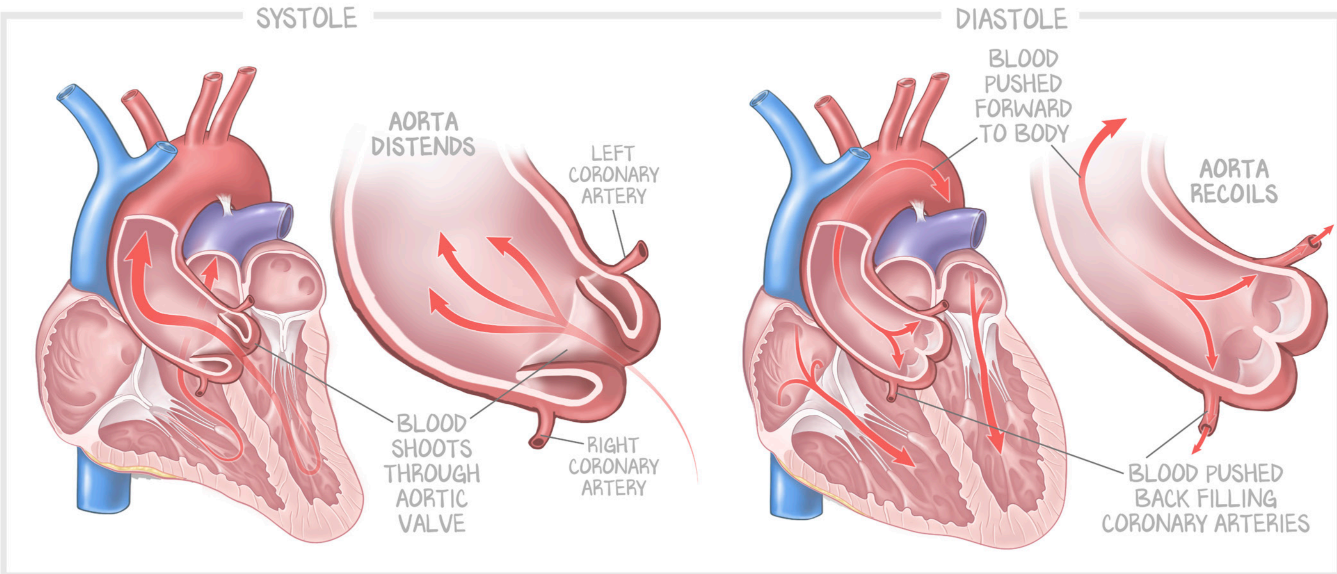

Figure 1.1: Coronary Artery Perfusion
Systole. When the myocardium contracts, the wall tension in the coronary arteries increases, and systolic contraction projects blood down the arterial system. The direction of flow is away from the ostia, and the resistance in the coronary arteries is very high. Because blood likes to follow the path of least resistance, and resistance is high in systole, it wouldn't make much sense to attempt to perfuse the coronary arteries during systole, anyway. (b) Diastole. When the ventricles relax, the wall tension in the coronary arteries decreases and the diastolic elastic recoil of the aorta directs flow into the ostia. . At normal heart rates, the heart spends two-thirds of its time in diastole and only one-third in systole. Therefore, coronary perfusion gets nearly double the perfusion time.

Coronary Artery Anatomy Primer

The coronary vasculature is derived from the aorta. There are **two coronary arteries**, a left one and a right one. They have branches, which must reach all of the heart muscle. There is significant variation from human to human in the coronary arteries that are responsible for perfusing a particular territory of muscle. The fact is that the heart doesn't care which branch of the aorta—the left coronary artery or the right coronary artery—brings blood to the heart's arterioles and capillary beds as long as the tissue is well perfused. But "anything can be anything" isn't a great way to start learning about the coronary vasculature. So we are going to remove ambiguity at the beginning, then escalate toward what is actually true.

Ultimately what we want you to learn is that the **coronary arteries share responsibility** and together perfuse the entire heart, and that **there is symmetry** between the left and right ventricles and the left and right coronaries.

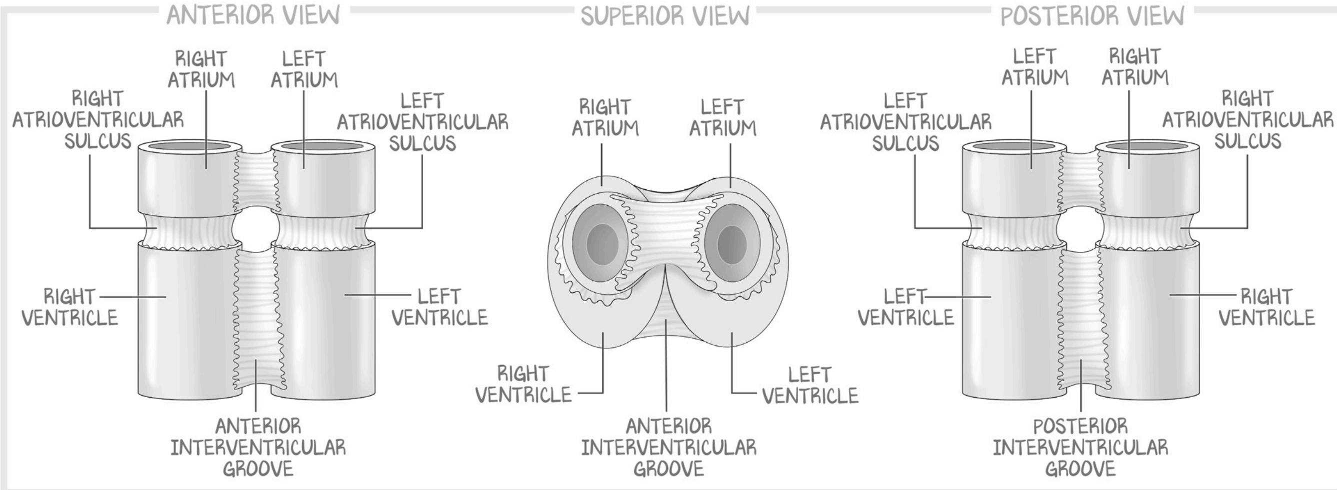

Figure 1.2: Highly Schematic Heart—Sulci and Grooves

This looks nothing like a heart. There are four cylinders, each representing a chamber—left atrium, right atrium, left ventricle, and right ventricle. They are discontinuous, separated by grooves and sulci. "Groove" and "sulcus" mean the same thing in the context of the heart, but we are going to use "sulci" for atrioventricular sulci and "groove" for interventricular grooves. Between the two ventricles in the front is the **anterior interventricular groove,** and between the two ventricles in the back is the **posterior interventricular groove**. Between the left atrium and left ventricle is the **left atrioventricular sulcus,** and between the right atrium and right ventricle is the **right atrioventricular sulcus**. Blood vessels travel on the **surface** of the heart, within the epicardial fat. Big blood vessels can travel **only in sulci or grooves.**

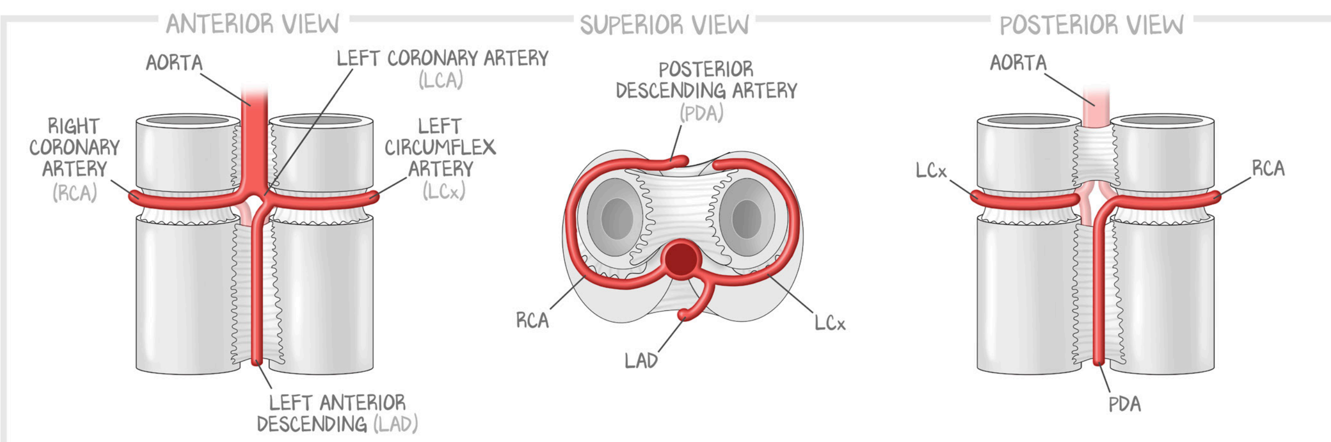

Figure 1.3: Big Blood Vessels Travel in Sulci or Grooves

The illustration of the blood vessels is very schematic. Blood vessels travel within the sulci and grooves. Blood vessels use the **sulci** to **wrap around** the heart and use the **grooves** to travel down the heart. After branching from the aorta, the **left coronary artery** immediately branches into two large vessels. One branch wraps around the left lateral side of the heart, moving from the front to the back within the left atrioventricular groove. This is "the circumflex artery." Even though there is no right circumflex artery, because the circumflex artery is a branch of the left coronary artery, it has been given the name **left circumflex artery**. The other branch descends the heart within the anterior interventricular groove.

Because it is a branch of the left coronary artery, it has been given the name the **left anterior descending artery**. The right coronary artery, akin to the left circumflex, wraps around the right side of the heart, from the anterior to posterior, within the right atrioventricular sulcus. It retains its name, **right coronary artery**, until it descends the posterior interventricular groove as the **posterior descending artery**.

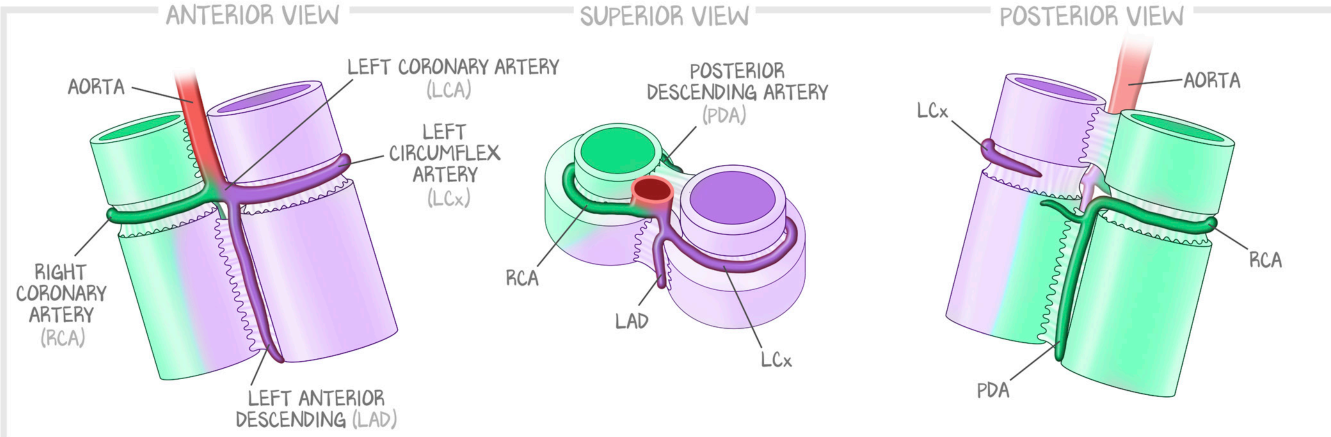

Figure 1.4: Left and Right Coronaries Share the Heart

There are going to be branches of these four main arteries, but what we want you to see first is that the left and right coronary arteries share the responsibility of the whole heart. And the "left circumflex" sure seems to mirror the "right coronary artery" (both wrap around the heart, under the atria, in the atrioventricular sulci). The "left" anterior descending seems to mirror the posterior descending artery (both run down the ventricles towards the apex within interventricular grooves).

Is It That Simple? They Just Share?

It is more complex than that. The heart isn't perfectly symmetrical (the left ventricle is bigger and beefier than the right ventricle), and there are more branches of these four main arteries.

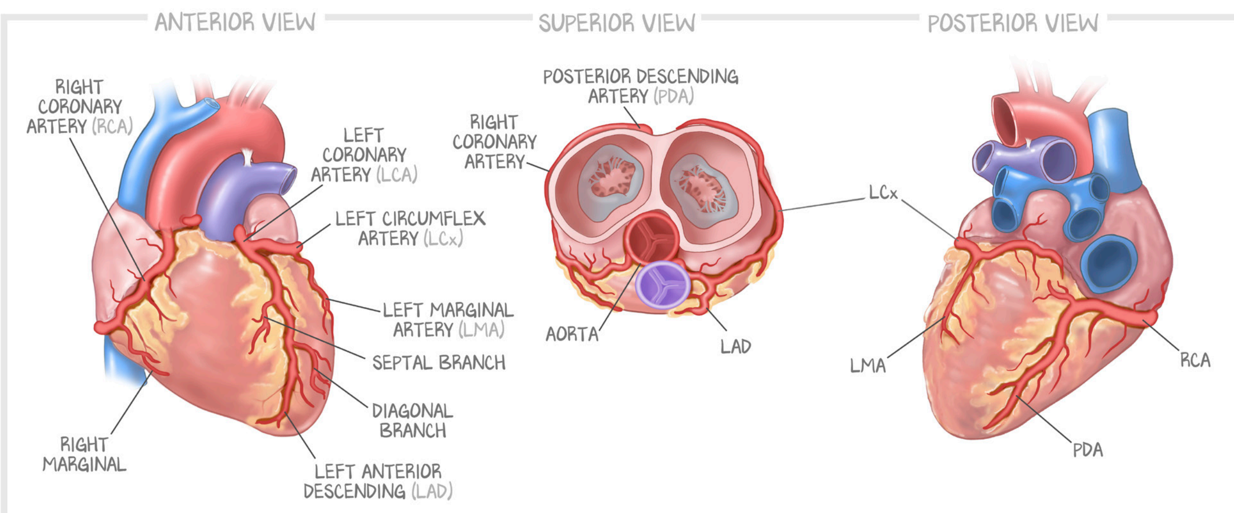

Figure 1.5: Real Heart Arteries

The **left coronary artery** gives rise to the **left anterior descending (LAD)** artery as it travels in the interventricular grooves. The LAD takes care of the front of the heart. It sends off **diagonal branches** to perfuse the larger left ventricle. The LAD also sends a large **septal branch** to perfuse the interventricular septum and the conduction system within. The **left circumflex** (LCx) sends off a **left marginal** branch that perfuses the lateral wall of the left ventricle. The **right coronary artery** has a very proximal branch that perfuses the **sinoatrial node** (sinoatrial branch). It is small and has been left out of the illustrations. Like the left circumflex, the right coronary artery has a marginal branch, called the **right marginal branch,** which perfuses the lateral wall of the right ventricle. The right coronary artery continues around the posterior of the heart within the right atrioventricular sulcus. At the posterior interventricular groove, the right coronary branches into the **posterior descending artery** and some unnamed branches that help the LCx with the posterior of the heart and the AV node.

There is so much variation in coronary anatomy that it is almost not worth teaching any one way. So we presented the cookie-cutter version, the "classic" anatomical arrangement. It's clean, it teaches all of the named arteries you are supposed to know, and it leaves out the complexities that just lead to confusion. But we don't want you to think that this is the only way it can be. The following two sections discuss features of coronary anatomy that come up on licensing exams. These are not the only two variations that matter, just the variations that are easily converted into licensing exam questions.

Heart Dominance and Heart Block

Heart dominance refers to the coronary artery responsible for the posterior descending. Most of the time, it is the **right coronary artery**. In that case, the patient is said to be **right heart dominant**. Some of the time, it is the **left circumflex** that gives rise to the posterior descending. In that case, the patient is said to be **left heart dominant**. In very few patients, the posterior descending artery has contributions from both the LCx and right coronary. That is a nondominant heart.

This is important in consideration of **heart block**, an arrhythmia. The atrioventricular node (detailed below) is the relay station for the electrical conduction system of the heart. The atrioventricular node is in the posterior of the left atrium. It and the bundles of His that arise from the AV node are perfused by the posterior descending artery. If the AV node is ill—nebulously defined right now as some amount of ischemic injury—heart block may result. Heart blocks are discussed in Electricity #4: *Arrhythmias*. In short, heart block is a bradycardic arrhythmia—a slow and pathologic heart rate—caused by impaired conduction through the AV node, from the atria to the ventricles. The point of heart dominance is not to help you deduce the lesion should you discover a heart block—just the opposite. Because of such great variation in anatomy, in the perfusion of the posterior descending, and therefore perfusion of the AV node, if you start with a heart block on an ECG, you cannot reliably deduce which artery is involved. Likewise, if you are told there is a lesion of either the LCx or the right coronary, you cannot be certain that either would cause a heart block. The only conclusion you can draw is if there is a heart block, and an angiogram demonstrates a lesion of either the LCx or the right coronary, don't be surprised.

That was a bunch of fairly confusing logic. The point is, don't associate AV block with a lesion of either the left circumflex (from the LCA) or the right coronary. Associate AV block with impaired filling of the posterior descending artery only.

Papillary Muscles and Their Arteries

The papillary muscles of the mitral valve hold their corresponding leaflets during systole, preventing them from prolapsing into the left atrium. There are two, one each for each cusp of the mitral (bicuspid) valve—the anterolateral and posteromedial. Much as in our story above, even though these are both left ventricular muscles, the blood supply to these muscles is yet another responsibility shared by the left and right coronaries.

Because the anterolateral is in the front and on the left lateral side, it may come as no surprise that the left coronary artery is responsible for taking care of it. But because the left coronary artery branches early, the **anterolateral papillary muscle** has a **dual blood supply**—branches from the LAD and LCx irrigate the anterolateral papillary muscle. Conversely, because the **posteromedial papillary** muscle is in the back and the middle, it is irrigated by **only the posterior descending** (from the RCA . . . usually).

In a myocardial infarction, the anterolateral papillary muscle is highly unlikely to fail because it would require simultaneous compromise of both the LAD and the LCx. However, only one vessel needs to fail to cause infarction of the posteromedial papillary muscle. Papillary muscles are made of cardiac myocytes, and cardiac myocytes need oxygen and glucose to function. Compromise of their blood flow, a heart attack, results in coagulative necrosis. **Papillary muscles rupture due to infarction.**

Furthermore, the chordae tendineae are the connective tissue that connects the papillary muscles to the mitral valve. Being connective tissue and not myocardium, they are far less vulnerable to ischemia than muscles are, so they don't tear due to infarction. We learned in Structure and Function #2: *Endocarditis* that bacteria like to get on valves, eat valves, and rupture chordae tendineae. **Chordae tendineae rupture due to infection.**

Coronary Venous Anatomy

The **coronary sinus** is the main vein of the coronary circulation. It is located on the **posterior** of the heart, in the **posterior coronary sulcus on the left**. All deoxygenated blood drains into the right atrium. All the veins superior to the heart drain into the superior vena cava, then the right atrium. All the veins inferior to the heart drain into the inferior vena cava, then the right atrium. The **cardiac veins** drain into their equivalent of the "coronary vena cava," the coronary sinus, then the right atrium. Because oxygen demand in the heart is so high, the venous concentration of oxygen in the coronary sinus is lower than anywhere else in the body.

The other coronary veins are less clinically significant but make for great anatomy shelf test questions. They rarely appear on licensing exams because coronary arteries are so much more important than veins. Coronary vein thrombosis effectively never occurs, and the coronary veins almost always do their job the way they are supposed to. So, lacking any clinical significance, they tend to get downplayed, except when anatomy is all you are studying. Be cautious, however, as the coronary veins are **not named** after the artery they mirror. They are linked to their coronary artery equivalent in the course they traverse. The coronary veins travel in the epicardial fat of the atrioventricular sulci and interventricular septa, alongside their coronary artery partner.

ARTERY	LOCATION	VEIN
Left anterior descending	Anterior interventricular sulcus	Great cardiac vein
Posterior descending	Posterior interventricular sulcus	Middle cardiac vein
Right coronary artery	Right atrioventricular sulcus	Small cardiac vein
Left circumflex	Left atrioventricular sulcus	Oblique vein of left atrium *and* posterior vein of left ventricle

Table 1.1: Vessels of the Coronaries

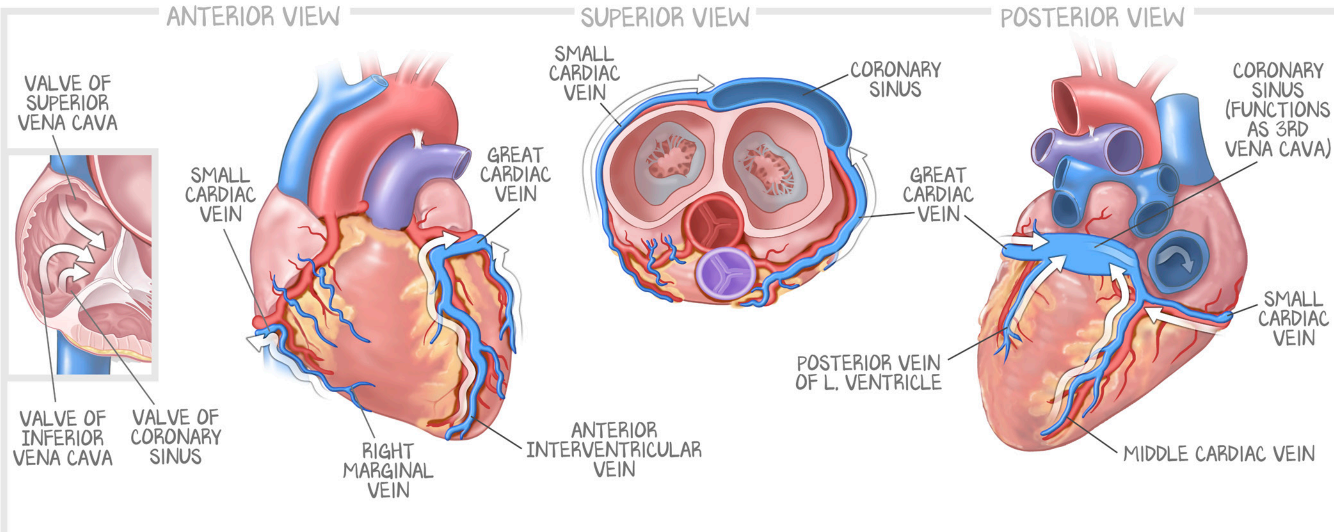

Figure 1.6: Veins of the Heart
The anterior view shows the pairing of the vein with the artery and the septum it travels in. The posterior view shows the pairing of the vein with the artery and where it courses. Notice that all of the veins drain directly into the coronary sinus.

The Electrical Conduction System

For the arteries, we were outside the heart—sulci and grooves. For the conduction system, we are inside the heart. But not inside the chambers where the blood is. We are now either **within the myocardium** or within the **fibrous tissue** that separates the atria from the ventricles, the **atrioventricular septum**.

That fibrous band of tissue is what the atria connect to. The atria are divided from each other by a non-fibrous septum made of myocardium. Myocardium conducts electricity. **Fibrous stuff does not.** All of the myocytes of the atrial myocardium are connected as a syncytium—gap junctions, adherens junctions, and desmosomes. All of the myocytes of the ventricles are connected to each other as a syncytium—gap junctions, adherens junctions, and desmosomes. The fibrous atrioventricular septum is what separates the atrial syncytium from the ventricular syncytium.

When the atria beat, they beat as one, at the same time. When the ventricles beat, they beat as one, at the same time. This is because when the electrical signal is propagated through a **myocardial syncytium**, action potentials are propagated through the gap junctions between myocytes at the intercalated discs. As long as a myocyte is in contact with another myocyte, the electrical signal will continue through to the next cell.

The atria and ventricles beat at different times. The fibrous band separates the atrial myocytes from the ventricular myocytes. No electrical signal can get from the atria to the ventricles. Yet somehow the atria and ventricles are coordinated, and the signal for both to contract comes from the SA node in the atrium. This coordination is allowed by specialized cells that penetrate the fibrous atrioventricular septum—the cardiac conduction system of the atrioventricular (AV) node. The signal originates at the **SA node**, then almost instantly propagates through the entire **atrial syncytium** and reaches the **AV node**. The AV node delays conduction briefly, allowing the atria to contract. The signal then arises on the other side of the atrioventricular septum as the **bundle of His** (pronounced "hiss") and traverses down the interventricular septum. From the bundle of His arise **Purkinje fibers**, right- and left-sided tracts of pacemaker cells that descend toward the apex and then ascend the lateral walls of their corresponding ventricles.

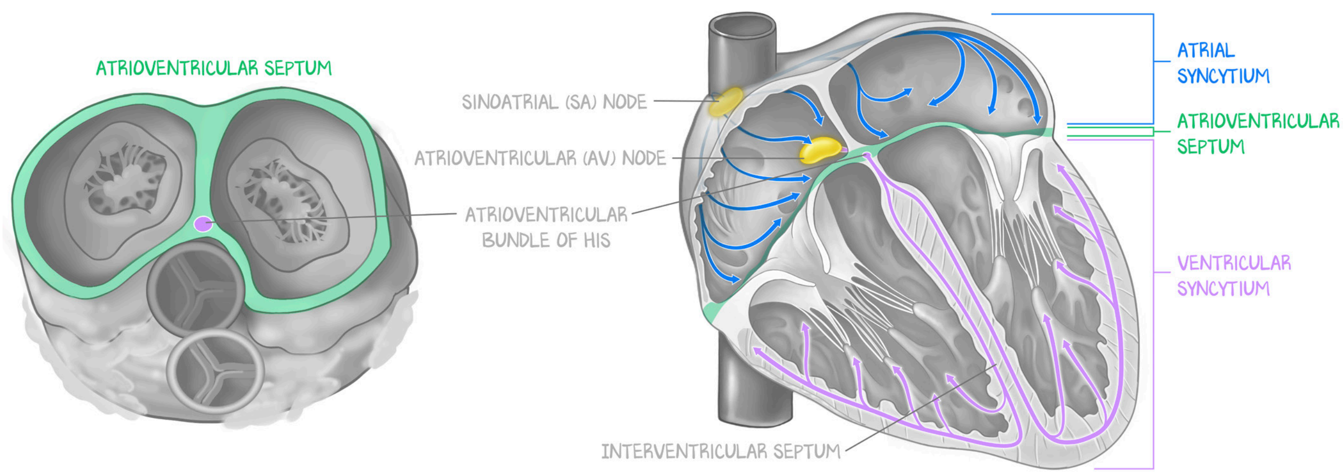

Figure 1.7: Electrical Conduction System
The atrioventricular septum (green) from the atria looking down, showing the fibrous rings of the valves and how the atrioventricular bundle (purple) runs through the middle of that fibrous structure. Otherwise, there is no connection between the atria and ventricles. When seen in longitudinal cross-section, we can preview the cardiac conduction system—from the SA node through the atria to the AV node (atrial syncytium), then from the AV node to the bundle of His, which gives rise to the Purkinje fibers.

These are the basics. In Electricity #2: *Conduction System*, we explore the details of the conduction system, cells, channels, and action potentials. In Electricity #3: *Visualizing the EKG*, we demonstrate how the timing of the conduction system can be recorded via line tracing and how you can link the coronary artery territories with the 12-lead. In Electricity #4: *Arrhythmias*, we explore intrinsic rates of different regions of the conduction system and what can happen to make things go awry. In Electricity #5: *Antiarrhythmias*, we explore how to manipulate action potentials to treat arrhythmias. Finally, in CAD #5: *Acute Coronary Syndrome*, we will put electricity and plumbing together.